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Update 1996/97

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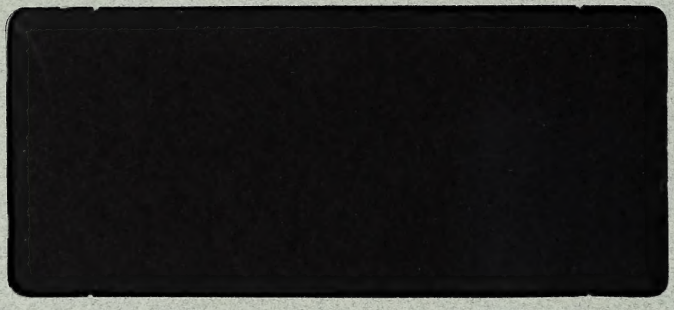

Manning Diversified Forest Products
Research Trust Fund
MDFP 7/97
Chemical Ecology and Management of
Of Forest Insect Pests
Update 1996/97

October 1997

By Dr. John H. Borden
Prof., Centre For Pest Management
Department of Biological Sciences
Simon Fraser University
Burnaby, British Columbia
Canada

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- Disclaimer -

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CHEMICAL ECOLOGY AND MANAGEMENT OF FOREST INSECT PESTS

NSERC Industrial Research Chair: Phase II

First Annual Report

1 October 1996 - 30 September 1997

Submitted to:

The Natural Sciences and Engineering Research Council,
Forest Renewal B.C., the Science Council of B.C.,

and the following industrial sponsors:

Ainsworth Lumber Co. Ltd., B.C. Hydro and Power Authority,
Bugbusters Pest Management Inc., Canadian Forest Products Ltd.,
Crestbrook Forest Industries Ltd., Finlay Forest Industries Inc.,
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MB Research, Northwood Pulp and Timber Ltd.,
Pacific Forest Products Ltd., Phero Tech Inc.,
Riverside Forest Products Ltd., Slocan Forest Products Ltd.,
TimberWest Ltd., Tolko Industries Ltd.,
Weldwood of Canada Ltd., West Fraser Mills Ltd.,
Western Forest Products Ltd., and Weyerhaeuser Canada Ltd.

by

John H. Borden, R.P.F., R.P. Bio.
Professor, Centre for Pest Management
Department of Biological Sciences
Simon Fraser University
Burnaby, B.C. V5A 1S6

15 October 1997

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Executive Summary

This is the first of five annual reports on Phase II of my Industrial Research Chair. Because Dr. Gerhard Gries, the junior Chair appointee, has now developed an independent research program, this report is confined to activities in my laboratory. An active collaboration with Dr. Gries continues, as it does with SFU chemist Dr. Keith Slessor and numerous other individuals. A new association developed with an SFU seed physiologist, Dr. Allison Kermode, promises to make research on the impact of seed bugs a very productive area.

During the year ending on 30 September 1997, the Chair supported in whole or in part 4 Postdoctoral Fellows or Research Associates, 3 Research Technicians, 4 Ph.D. Students, 1 M.Sc. Student, 8 Master of Pest Management (M.P.M.) Students, and 13 Research Assistants. Two Ph.D. students and 4 M.P.M. students received their degrees during the past year.

The Chair research focuses on the chemical ecology and management of forest insect pests in western Canada. A major effort involves the use of coupled gas chromatographic-electroantennographic detection (GC-EAD) analysis to identify semiochemicals (message-bearing chemicals) that mediate the behaviour of terminal weevils, bark beetles, wood-boring beetles, and true bugs. The Chair philosophy is to take new discoveries into the field rapidly, and to work with industry to bring any new promising materials or methods to operational status with dispatch.

Results of interest during the past year include: 1) confirmation that a post-wounding rise in the ratio of terpenes to resin acids in interior spruce leaders is associated with less viscous resin that could pitch out white pine weevil attacks; 2) demonstration that fertilization of Sitka spruce does not cause a lowered density of outer resin ducts, and hence does not diminish the first line of constitutive resistance to the white pine weevil; 3) indication that traumatic resinosis caused by the white pine weevil is primarily caused by physical wounding rather than microbial invasion; 4) finding that traumatic resinosis in spruces can be caused by lygus bug feeding, but not by adelgids; 5) reconstruction of a blend of synthetic host volatiles that induces a positive orientation response by white pine weevils in the laboratory; 6) finding that human intervention by logging in northern interior

forests results in no more intense weeviling of spruce regeneration than occurred in the past after natural fires; 7) identification of 20 non-host angiosperm bark volatiles that can be perceived by the antennae of bark and ambrosia beetles; 8) finding that a "cocktail" of 16 of the above non-host volatiles (4 monoterpenes also present in conifer bark deleted) can accentuate the effect of the antiaggregation pheromone verbenone in protecting lodgepole pines from attack by the mountain pine beetle; 9) discovery that the bark beetle pheromone frontalin occurs in the bark of alders, and that conophthorin occurs in the bark of maples, poplars, aspens and particularly birches; 10) demonstration that conophthorin is a repellent for both mountain pine and Douglas-fir beetles; 11) first detection of the pheromone *exo*-brevicomin in an *Ips* species; 12) demonstration using pine engravers as an indicator species that a natural neem-based pesticide transloctates in lodgepole pines at least as high as 9 m from a basal axe-frill application; 13) elucidation of the historical infestation dynamics of the western balsam bark beetle in a high-elevation stand; 14) finding that no interference occurs between stands baited for both spruce beetles and western balsam bark beetles, meaning that co-baiting of stands can be done if desired; 15) first absolute proof of primary attraction of the fir engraver by demonstrating response to traps baited with a blend of synthetic host volatiles; 16) inhibition by green leaf volatiles of response to aggregation pheromone in the ambrosia beetle *Gnathotrichus sulcatus*; 17) inhibition (91 and 88% for males and females, respectively) by non-host angiosperm bark volatiles of the response of striped ambrosia beetles to pheromone-baited traps; 18) identification of 11 previously unknown host volatiles that excite the antennae of cerambycid and byprestid wood-boring beetles; and 19) description by scanning electron microscopy of the impact of feeding by the western conifer seed bug on Douglas-fir seeds. Many projects are in the start-up phase and can be expected to yield interesting and useful results in the future.

Productivity of the Chair research program is evidenced by the publication since 1 October 1996 of: 8 papers in refereed journals and the acceptance of 9 more in press; one chapter; 2 non-refereed papers; and the submission of one provisional U.S. Patent application (not on FRBC-funded research). Twenty nine listed items document my active professional life, including numerous teaching and service roles outside of Chair-supported research.

The Chair is in a healthy financial position. In part because of two new grants from Forest Renewal B.C. for wood-borer and seed bug research, revenues in the year ending on 30 September 1997 totaled $500,563. Expenditures totaled $471,500, leaving a surplus of $29,063.28. This will be used, along with new revenue to replace used equipment and to upgrade computing, biochemical and gas chromatographic capabilities.

Acknowledgments

I thank the many academic, government and industrial colleagues who have collaborated with me or my students, or who have provided advice or some other type of assistance. I have endeavoured to include all such input in the text of this report; I take full responsibility and apologize for any omissions. Maintaining a large, productive research program would not be possible without major funding, and I am most grateful to the three government agencies and 22 industries listed on the cover page for their generous support, and for trusting me to make decisions on research, personnel and administration that I feel will maximize the return on their investment. In this regard I especially thank my project administrators, Dr. Pierre-Richard Gaudreault of NSERC and Mr. Kevin Carvill, R.P.F. of the Science Council of B.C. They have shown remarkable administrative flexibility and respect for the value of my research program, even though my lack of administrative skill and my inclination to attempt to bend the rules must surely be a source of some annoyance.

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I. INTRODUCTION

This is the first Annual Report of the second, five-year phase of my NSERC Industrial Research Chair. The objectives of Phase II, as outlined in the proposal for renewal of the Chair were to:

1. use GC-EAD technology in collaboration with Dr. Gerhard Gries of SFU to identify compounds in the bark of at least 6 species of non-host trees that are potential repellents for 6 species of bark beetles, 2 species of terminal weevils, 3 species of ambrosia beetles and numerous species of cerambycid and buprestid woodborers;
2. use similar methodology to identify potential host attractants for terminal weevils and woodboring beetles;
3. conduct field experiments designed to test the ability of non-host volatiles to deter the above insects from responding to attractant-baited traps, and for host volatiles to attract terminal weevils and woodboring beetles;
4. determine the potential efficacy of non-host volatiles in protecting trees, stands and logs from attack by damaging insects;
5. work with industry in developing operational protocols for using repellent non-host volatiles in forest pest management;
6. work with industry to incorporate new strategies and tactics using attractive semiochemicals alone or in combination with repellents to manipulate pest insect populations;
7. continue to work with Dr. Gries and Dr. Keith Slessor of SFU to identify the pheromones of selected insect pests of forests, forest products, seed orchards and nurseries; and to
8. maintain a sufficiently large and flexible laboratory to enable rapid initiation of "on-demand" research as opportunities arise and demand is expressed by industry.

Some modifications to these objectives have already occurred. For instance, Forest Renewal B.C.'s (FRBC) request that I apply separately to fund research on woodborers has delayed initiation of this work. I elected to continue a project on impact assessment of the western conifer seed bug and

have successfully sought separate funding from FRBC for that project as well. The appearance of the right student to conduct ecological research on an introduced pest, the poplar and willow borer has led to a project with direct relevance to biodiversity. Some research on host resistance to terminal weevils does not specifically follow the original objectives. However, in general the research is on track, on time, on budget, and already productive.

This report contains the research components of the 6-month interim reports for two FRBC projects on wood-borers (Section II, C) and seed bugs (Section II, D). It also encompasses the final report for the $75,000 contribution from FRBC (FRBC ref. #HQ96233-RE and SCBC ref. #FR-96/97-837) to the $300,000 NSERC CRD grant package that constitutes the 5-year stable funding base for the Chair.

II. RESEARCH REPORT

A. TERMINAL WEEVILS

- Postdoctoral Fellow, Dr. Elizabeth Tomlin, has continued to lead this project in collaboration with Dr. René Alfaro of the Pacific Forestry Centre, Canadian Forest Service, Victoria. Dr. Tomlin has maintained her focus on the mechanisms of resistance to *Pissodes strobi* in both Sitka and interior spruce in B.C. She completed a manuscript (now in press in Tree Physiology) on the morphology of induced resistance following simulated weeviling by mechanical wounding of interior spruce, and has worked with Research Assistant, Eva Antonijevic to expand the data base on changes in terpene and resin acid composition in interior spruce following wounding. The hypothesis that a post-wounding rise in the ratio of terpenes to resin acids is associated with a change to less viscous resin that can pitch out new attacks has been upheld by this research. A manuscript is in preparation on this work.
- In collaboration with Dr. Alfaro and Pacific Forest Products Ltd., Dr. Tomlin conducted a study in which four levels of fertilization (high, medium, low and none) were applied to 3-year-old seedlings (Big Qualicum provenance). The seedlings from each treatment were divided into four groups of eight. One group was wounded in early May, and sampled in early June for the

traumatic wound response. Two groups were used in feeding trials in early May, and the fourth group was sampled in early August to examine the constitutive resin ducts. The magnitude of the traumatic wound response increased significantly with level of fertilization. The density of inner resin ducts decreased as the level of fertilization increased, but the absolute number did not differ between treatments. This indicates that inner resin ducts do not proliferate as the diameter growth increases with fertilization. The number of outer resin ducts increased with level of fertilization, and the density remained the same, indicating that outer resin duct formation (and hence the capacity for constituted resistance) keeps up with diameter growth. Results of the feeding trials were inconclusive, as weevils preferred material from either the highest level of fertilization or the control discs in an agar-disc bioassay, the low level in a twig bioassay, and the medium level in a potted-tree bioassay.

- At UBC's Malcolm Knapp Research Forest, Dr. Tomlin used a small drill to wound the leaders of 64 shaded and 64 unshaded Sitka spruce trees from two stocking types on 5 May 1997. Eight trees in each treatment and stocking type were sampled 7, 23, 59, and 98 days after wounding. Thirty two unwounded trees from both treatments and stocking types were sampled on day 98 as controls. By day 98, unshaded trees had a significantly greater wound response than shaded trees. The density of inner resin ducts was not affected by shading, but unshaded trees had higher absolute numbers of inner resin ducts. Both number and density of outer resin ducts were greater in unshaded than shaded trees. In 1996, when wounding was done after shoot elongation, the first traumatic resin duct in unshaded trees was observed on day 9, and in shaded trees on day 35. In 1997, when wounding was done before budburst, the first traumatic resin duct was observed on day 7 for both shaded and unshaded trees, indicating a quicker response in the case of shaded trees.
- To test for the effect of different elicitors of the traumatic wound response, four wounding treatments were applied to leaders of emblings at the UBC Research Forest. These were aseptic drilling, drilling plus chitosan, weevils alone and an unwounded control. Each treatment was replicated 10 times. After the treatment was applied, the leaders were protected with mesh bags to

prevent any natural attack by weevils or other insects. After five weeks, two portions of the leader from the area of wounding were cut, one for histological examination, and the second for analysis of resin components. There was no significant difference in the magnitude of the wound response score between the three wounding treatments, although all three were significantly higher than the control. Traumatic resin canals took longer to form in the weevil treatment than in the two treatments that involved drilling. There was also a significant reduction in radial growth in the weevil treatment that was not observed in the two mechanical treatments.

- To examine the capacity of insects other than white pine weevils to induce traumatic resinosis two experiments were done. In the first, five-year-old Sitka spruce seedlings were caged with weevils alone, lygus bugs alone, weevils and lygus bugs, or no insects. Each treatment was replicated eight times. After one month, the leaders were cut, and examined histologically. In addition, the number of feeding and oviposition punctures made by weevils were counted. There was no external evidence of lygus bug damage. The wound response to lygus bugs alone was greater than in the control, but less than the response to weevils or a combination of lygus bugs and weevils. In the second experiment 12 branches were caged on each of 10 interior spruce trees. On each tree, 3 branches had weevils alone, 3 had spruce gall adelgids alone, 3 had a combination of the two, and 3 had no insects. One branch from each treatment was sampled in May, June and July from each tree. Histological analysis showed that there was no wound response to adelgids alone. The responses to weevils with or without adelgids was the same. In these experiments, these were significantly fewer feeding and oviposition punctures made by weevils in the presence of lygus bugs or adelgids than on seedlings with weevils alone. We plan to investigate whether this is due to biochemical alteration of the host or to interference competition by the sucking insects.
- Following a lead suggested by the work of Ph.D. student, Jorge Macias-Samano working on bark beetles of grand fir, and drawing on the results of coupled gas chromatographic electroantennographic detection analysis (GC-EAD) by Research Technician Regine Gries, Dr. Tomlin has formulated a blend of antenally-active compounds in the natural component ratio

found in spruce twigs. This blend was moderately attractive in laboratory bioassays in vertically-oriented Y-tube olfactometers. When myrcene, by far the most prominent volatile in flushing buds, was added to the blend, attraction was enhanced. Attraction of females was enhanced even further by the addition of grandisol and grandisal to the blend. These two compounds are pheromones of the boll weevil, and are produced in significant amounts by male white pine weevils. However, when tested alone in the past, they induced no attraction. A field trapping experiment with the new blends of host volatiles and candidate pheromones deployed in pitfall and multiple-funnel traps was set up in May 1997 in collaboration with Dr. Alfaro at Jordan River, B.C. Very few weevils were captured, probably because the experiment was set up too late to catch the spring dispersal flight. Plans are already underway to conduct a similar experiment in 1998 commencing in March or April.

- In April 1997 Mr. Troy Kimoto successfully defended his Master of Pest Management (M.P.M.) thesis in which he demonstrated that the levels of white pine weevil impact in natural interior spruce stands following forest fires in the McGregor Model Forest were similar to those in replanted stands following logging. Thus human intervention has not altered the impact of the weevil. A manuscript on this work will be written in 1998, probably for submission to either the Canadian Journal of Forest Research or Forestry Chronicle.
- Ms. Julie Brooks, proprietor of Forest Health Management, worked in our laboratory for eight weeks this summer in an FRBC-funded project run by Dr. Lorraine Maclauchlan, B.C. Forest Service, Kamloops, investigating the nature of oviposition deterrents produced by the lodgepole terminal weevil, *Pissodes terminalis*.

B. BARK BEETLES

- Ph.D. student Dezene Huber, working in collaboration with Ms. Gries and Research Associate Dr. Harold Pierce, has now identified 20 simple volatiles in the bark of non-host angiosperm trees that have been shown by GC-EAD analysis to excite the antennae of several species of coniferophagous bark beetles. The identified compounds are: toluene, 3-hexanone, 2-hexanone,

hexanal, hexanol, heptanal, α-pinene, benzaldehyde, β-pinene, 3-carene, limonene, benzylalcohol, phenylacetaldehyde, salicylaldehyde, guiacol, nonanal, (*E*)-2-hexenal, octanoic acid and methylsalicylate. In randomized block field trapping experiments utilizing multiple-funnel traps, all 20 compounds were tested as potential disruptants against two model species of bark beetles, the Douglas-fir beetle in the spring and the mountain pine beetle in the summer. The former experiments were done in collaboration with Mr. Ed Senger of the B.C. Forest Service in Lilloet, and the latter were set up with the aid of the Weyerhaeuser Canada forestry staff, particularly Messers Brian Drobe and Jason Kennedy, in Princeton. Results on these two pilot species will be used to design research on other tree killing bark beetles, such as the spruce beetle and the western balsam bark beetle. At the time of writing, the many captured beetles were still being sexed and counted.

- To determine whether the cocktail of non-host angiosperm bark volatiles (minus the four monoterpenes, α-pinene, β-pinene 3-carene, and limonene, which are constituents of conifer resin) could be used as an adjuvant to accentuate and stabilize the activity of the antiaggregation pheromone, verbenone, Mr. Huber set up a 19-replicate tree-baiting experiment in the valley of Wolfe Creek near Princeton, B.C. Treatments were: a standard mountain pine beetle tree bait (Phero Tech Inc.), a tree bait with verbenone released at a low dose (ca. 1 mg per day), a tree bait with the cocktail released at ~ 300 mg per 24 h, and a tree bait with both verbenone and the cocktail. Attack on the trees was monitored every week. All trees with the tree baits were mass attacked within the first week after baiting on 25 July. All three antiaggregant treatments deterred attack, despite the presence of the potent baits. The verbenone and cocktail treatments were gradually overcome by the beetles, while the combination of verbenone and the non-host volatiles strongly deterred attack for most of August. The results of this and other experiments suggest that we are well on the way to developing operationally effective deterrents to attack by tree-killing bark beetles.
- One astounding result from Mr. Huber's work is the discovery of two well known pheromones of coniferophagous bark beetles in the bark of several angiosperm tree species. The attractive

pheromone, frontalin is found in the bark of two species of alder, and the generally repellent pheromone conophthorin is found in the bark of four species, with very large amounts (12% of the total bark volatiles) occurring in paper birch. In field trapping experiments, conophthorin was shown for the first time to be repellent to both the Douglas-fir beetle and the mountain pine beetle. The results of this study were presented by Mr. Huber at the July 1997 meeting of the International Society of Chemical Ecology in Vancouver, and a manuscript is in preparation for publication in the Journal of Chemical Ecology.

While preparing for her Ph.D. thesis defense (successful in May 1997), Dr. Therese Poland continued to work with Ms. Gries and Dr. Pierce on the identity of a strongly antennally-active compound that is present in the volatiles captured from male *Ips tridens*. Late in March 1997 this compound was identified as *exo*-brevicomin, the first time this pheromone, which is characteristic of the genera *Dendroctonus* and *Dryocoetes*, has been found in the genus *Ips*. Following Dr. Poland's departure for a research position with the U.S. Forest Service in Michigan, *exo*-brevicomin was tested alone and in combination with two attractive pheromones of *I. tridens* in two field trapping experiments set up south of Brookmere, B.C. The results of this experiment are still being analyzed.

- In late fall 1997, and after two discouraging field seasons, Ms. Marie Duthie's M.P.M. thesis fell neatly into place. Pine engravers, *Ips pini,* matured and emerged in much lower numbers from lodgepole pine bolts taken from trees that had been treated with a neem-based formulation in a basal axe frill, felled one week later, and allowed to be attacked by pine engravers over the next six weeks. Success of the brood was strongly inhibited at least as high as 9 m (and probably 15 m) above the axe frill. These results demonstrate that this environmentally-friendly botanical pesticide can be translocated high in the bole, that it is persistent in the sapwood and that it has a disruptive effect on pine engraver larval development. The potential future of neem for use against tree-killing bark beetles now looks much brighter. A manuscript on this research will be submitted to the Journal of Economic Entomology some time in 1998. Ms. Duthie began work as a forest entomologist for Bugbusters Pest Management Inc. in Prince George, B.C. in May 1997.

- Master of Pest Management student Leroy Harder is finalizing his thesis work with Dr. Maclauchlan on the western balsam bark beetle, *Dryocoetes confusus*, in the Sicamous Creek alternative silviculture systems research site. He has documented significant mortality caused by the beetle for many years, has reconstructed the infestation dynamics, and has shown that pre-logging pheromone baiting of patch and group selection cuts has the potential to reduce beetle populations greatly. Mr. Harder reported on this work at the Western Forest Insect Work Conference in Prince George in April 1997.
- In October 1996, Finlay Forest Products hosted Master of Pest Management student Matthew Greenwood and me at Oselinka Camp, northwest of Williston Lake, while we, with labour assistance provided by Bugbusters Pest Management, evaluated Mr. Greenwood's experiments on co-baiting stands for spruce beetles, *Dendroctonus rufipennis*, and the western balsam bark beetle. There was no evident interspecific interference between the baits when they were placed at 33 m centres. Data on the efficacy of the baiting programs as well as on the spatial dynamics of attack are being analyzed. The results of a further experiment testing three doses of frontalin as tree baits for the spruce beetle, set up in the Prince George area in 1998, are also being analyzed. As a result of contacts established during his field work, Mr. Greenwood was able to obtain valuable industrial experience working in operations for Finlay Forest Products in the summer of 1997.
- Ph.D. student Jorge Macias-Samano prepared and submitted a manuscript to the Journal of Chemical Ecology on primary attraction of the fir engraver, *Scolytus ventralis*, to a blend of volatiles from grand fir. This is the first demonstration of attraction to any defined semiochemical stimulus in this species. Mr. Macias-Samano's methods and results have stimulated similar research on terminal weevils and other bark beetles, and will be of great assistance in expediting our newly-initiated research on wood-borers. In his final field season of research, Mr. Macias documented a weakly negative interaction in attack success by the fir engraver and its secondary associate, *Pityokteines elegans*, demonstrated that semiochemical-based interaction occurs between the two species, and showed that pheromone-induced attack by *P. elegans* can result in

reduced attack success by the fir engraver. A mid-November thesis defence is planned, after which Mr. Macias will leave immediately for a research and teaching position in a government-run ecological institute in southern Mexico.

- M.P.M. student Nicole Jeans began her research project in 1997 evaluating two alternative pheromone formulations in an attempt to improve the operational tree baits for the western balsam bark beetle, *Dryocoetes confusus*, currently marketed by Phero Tech Inc. The current operational baits contain only (±)-*exo*-brevicomin, while the alternatives (based on optical isomers) are a 9:2 blend of (+)-*exo*-brevicomin: (±)-*endo*-brevicomin and a 9:1 blend of (+)-*exo*-brevicomin: (+)-*endo*-brevicomin (the true pheromone). The alternative baits were deployed at three release rates in a 30-replicate field-trapping experiment, and in an 18-replicate tree-baiting experiment to determine whether the cost of the more optically-pure alternatives could be reduced to a level competitive with that of *exo*-brevicomin, while maintaining or increasing the efficacy of the baits. These experiments, set up south of Brookmere, B.C. with the assistance of Mr. Bob Foster of Tolko Industries Ltd., Merritt, B.C., are still being evaluated. Semi-operational grid-baiting experiments are planned for both northern and southern B.C. in 1998, depending on the results of the 1997 research. This project is funded in part by a one-year FRBC grant to Phero Tech Inc.
- Comparative production dynamics of the pheromones of the pine engraver, *Ips pini*, and the mountain pine beetle, *Dendroctonus ponderosae*, will be studied by Ms. Deepa Pureswaran, who began her graduate studies in September 1997. This work will employ GC and GC-EAD techniques to establish the rates of production over time of at least two pheromones of *I. pini* and four of *D. ponderosae* under controlled laboratory conditions. It will establish the onset, peak and termination of pheromone production in relation to attack phase of each species, will elucidate the potential role of pheromones in resource partitioning by both species, and will provide background data useful in understanding the role of semiochemicals in managing these species. It will also provide Ms. Pureswaran with critical training that she will need for her Ph.D. project (see below).

- Concurrent with her M.Sc. research, Ms. Pureswaran will begin to investigate the role of pheromones and host volatiles in the maintenance of host specificity and reproductive isolation of four species of tree-killing bark beetles: the mountain pine beetle, *Dendroctonus ponderosae*; the spruce beetle, *D. rufipennis*, the Douglas-fir beetle, *D. pseudotsugae*, and the western balsam bark beetle, *Dryocoetes confusus*. Volatiles will be extracted from pheromone-producing beetles of each species and host volatiles will be captured from the respective trees infested by each species: lodgepole pine, *Pinus contorta* var. *latifolia*; Engelmann spruce, *Picea engelmannii*; Douglas-fir, *Pseudotsuga menziesii*; and subalpine fir, *Abies lasiocarpa*. The volatiles will be analyzed by GC and GC-EAD, testing for potential bioactivity against each con- and heterospecific beetle. Antenally-active compounds will be tested in wind-tunnel and field trapping and tree-baiting experiments. The results will reveal any potential new attractants, will disclose how semiochemicals maintain host specificity and reproductive isolation by the four species of bark beetles, and will potentially lead to new operational attractants and repellents to be used against these tree-killing insects.

C. WOOD-BORING BEETLES (FRBC ref. #PA97511-ORE)

This project is now wholly-funded for five years commencing on 1 April 1997 by Forest Renewal B.C. Two main insect targets of this research are ambrosia beetles that cause well over $100 million in damage to B.C. timber each year, and the larger wood-boring beetles in the families Cerambycidae and Buprestidae that cause severe but still largely unquantified damage to the lumber industry, particularly in the B.C. interior and Alberta. The ambrosia beetle sub-project is under my primary direction with operational management by Research Technician Leslie Chong. The wood-borer sub-project is run by Dr. Rory McIntosh who joined my laboratory in June 1997, immediately following the successful defense of his Ph.D. thesis at UBC.

Ambrosia Beetles

Research on ambrosia beetles was done in 1996-7 under a separate Technology B.C. grant. Master of Pest Management student Keith Deglow completed the data analysis on his 1996 field experiments that demonstrated a profound disruptive effect of six-carbon green leaf alcohols on pheromone response by *Gnathotrichus sulcatus* and *G. retusus*, and a tantalizing enhancement effect of certain green leaf aldehydes. His thesis was successfully defended in June 1997, and a manuscript on this work is planned for submission to a refereed journal in 1998. Mr. Deglow is currently working as a pest management specialist for Phero Tech Inc.

GC-EAD analyses begun in the spring of 1996 demonstrated that antennae of the striped ambrosia beetle, *Trypodendron lineatum*, are stimulated by the same angiosperm bark volatiles that excite the antennae of bark beetles. Additional GC-EAD work on *T. lineatum* and *Gnathotrichus* spp. continued in 1997 and further analyses will be done in 1998. Under the supervision of Ms. Chong, a series of field trapping experiments was initiated in the spring of 1997 to begin to test the effect of these volatiles on the response of the beetles to their respective pheromones. Work on *T. lineatum* began in April and phased into experiments on *G. sulcatus* in July. No work was done on *G. retusus* in 1997. The results to date are most complete for *T. lineatum*. They are fascinating and show great promise of yielding new operationally useful management tools. When each of the 20 non-host volatiles was tested singly or as a cocktail in combination with lineatin, the results ranged from a 59 and 63% reduction in trap catches for males and females, respectively, caused by salicylaldehyde, to a 1.9 and 1.7 times increase in trap catches for males and females, respectively, caused by guiacol. The cocktail of all 20 compounds caused a 67 and 70% reduction in response for males and females, respectively. When the 4-component conifer monoterpene fraction was separated from the remaining 16 compounds, the conifer fraction was inactive. However, the 16-component cocktail caused a 91 and 88% reduction in catches for males and females, respectively, as opposed to 87 and 80% for the 20-component cocktail. At least one and possibly two additional years of research will be required before the trapping experiment results are complete enough to publish. During that time, however, we will also be

working on the development of sprayable, flowable or slow-release formulations that could be used to protect logs from attack. This research will be coordinated with that on cerambycid and buprestid wood-borers, with the objective of developing a generic repellent treatment.

2. Cerambycid and Buprestid Beetles

- Dr. McIntosh began his immersion into the world of wood-borers by accompanying Phero Tech Field Technician Patrick Kohn to operational field trapping locations in the B.C. interior to review current field trapping practices and to become familiar with major wood borer pest species. During this time, potential field-trapping areas were located for late season trapping studies in 1997. Interior sites selected for preliminary trapping experiments were: Gorman Bros. sawmill in Westback and Tolko mill in Merritt, the site of a fire in July 1997. Other potential sites (1998) include the Riverside mill in Lumby, the Weyerhaeuser mill in Okanagan Falls, and the Lytton Lumber Limited mill in Lytton. Also, the 1997 Lytton forest fire area could provide an excellent study site in the future. Additional potential sites in northern B.C. and Alberta will be explored in 1998. The most prevalent and apparently damaging target species identified (in collaboration with Phero Tech) were: (Cerambycidae), sawyer beetles, *Monoachamus scutellatus*, *M. clamator*, *Xylotrechus longitarsus*, and *Asemum* spp.; and (Buprestidae) the golden buprestid, *Buprestis aurelenta*, the fir borer, *Melanophila drummondi*, the sculpted pine borer, *Calcophora virginiensis*, and *Dicerca tenebrosa*. Other species that may be considered are: (Cerambycidae) *Arhopalus* spp., and (Buprestidae) *Chrysobothris* spp.
- Research in 1997 has focussed on host volatiles that could be used as adjuvants to the standard ethanol plus α-pinene bait that is only moderately effective. Bolts were taken from freshly-felled logs of the following species: grand fir, *Abies grandis*, subalpine fir, *Abies lasiocarpa*, Douglas-fir (coastal and interior), *Pseudotsuga menziesii*, ponderosa pine, *Pinus ponderosa*, lodgepole pine, *Pinus contorta* var. *latifolia*, and interior spruce, *Picea engelmannii ex glauca*. In collaboration with Ms. Gries and Dr. Pierce, bark-wood sections were split from these bolts, placed in glass chambers, and the volatiles collected on Porapak Q. Extracts of the volatiles stripped from Porapak Q were analyzed by GC and GC-EAD on available species, *Monochamus*

spp. *X. longitarsus*, *B. aurulenta*, *M. drummondi*, *C. virginiensis* and *D. tenebrosa*. Antennally-active volatiles were identified by GC-mass spectroscopy (MS). There was considerable interspecific variability in perceived compounds and many still remain unidentified. However, a cocktail of 11 identified compounds that were antennally-active to all species was tested alone, and with the standard bait in 10-replicate field experiments using multiple-funnel traps, deployed in randomized blocks at the Tolko (Merritt) and Gorman Bros. (Westbank) sites. As in much seasonal research, this effort proved to be too little too late. No traps, including those baited with ethanol and α-pinine, captured more wood-borers than unbaited control traps. By the 1998 field season, more complex and possibly species-specific blends should be available for testing much earlier in the summer.

- Several other activities are ongoing. Because wood-boring beetles are attracted to fire-damaged timber, Dr. McIntosh took advantage of an experimental slash burn at UBC forest to throw logs of each of the above species into the fire. Volatiles captured from the burned logs are currently under analysis, and could provide additional components of improved baits in the future. As a spin-off from this research, I have talked with Dr. Jeremy McNeil of Laval University who has demonstrated that female black army cutworms, *Actebia fennica*, are attracted to smoke volatiles. Because these cutworms are major pests of new plantations, and because there is an opportunity to wed Dr. McNeil's expertise and supply of colony-reared insects with our GC-EAD capability and knowledge, we plan a collaborative project designed to identify the major attractants for *A. fennica*. Dr. McIntosh is adapting a used trailer for mass-rearing of field-collected woodborers (see Section VII), and is attempting to set up a laboratory colony of *Monochamus* spp. He has demonstrated that given a sufficient supply of branch tips for maturation feeding, they will oviposit on logs in the laboratory. Dr. McIntosh is also spending a considerable amount of time learning to identify and sex all species of important wood-borers, and is assembling a reference collection of these insects.

- No research has yet been done on the effect of non-host angiosperm bark volatiles on host selection by coniferophagous wood-borers. A new graduate student, possibly Jeremy Allison, will begin work on this subject in 1998.

D. IMPACT ASSESSMENT OF THE WESTERN CONIFER SEED BUG

(FRBC ref. #PA97510-ORE)

This project is now wholly funded for four years commencing on 1 April 1997 by Forest Renewal B.C. The new project is a collaborative effort between me, Dr. Allison Kermode, an Associate Professor and seed physiologist in SFU's Department of Biological Sciences, and Dr. Robb Bennet, Seed Orchard Pest Management Officer in the B.C. Forest Service.

- Under a minor services contract with Dr. Bennett, ending on 31 March, 1997, Ms. Anne Savoie worked on characterizing and quantifying the damage caused by the western conifer seed bug, *Leptoglossus occidentalis*. Evidence for the impact of the bug has been circumstantial to date, based mainly on failed cone crops in seed orchards where the bug is prevalent. Assessment of seed by x-rays can disclose partially-filled or empty seed, but can not separate damage caused by seed bugs from that caused by metabolic failure or other agents. Various methods of dying seeds or cones are imprecise at detecting the past presence of seed bugs based on enzymatic residues left on the seed coat or cone scales. Therefore, we have turned to scanning electron microscopy (SEM) as a means of precisely describing the damage. Ms. Savoie exposed Douglas-fir seeds to feeding by each of the five nymphal instars of seed bugs as well as each sex of the adults. She then split the seed, and in cooperation with Ms. Leslie Manning of the Pacific Forestry Centre analyzed the damage by SEM. Comparative analyses were done by x-rays, light microscopy and weight loss measurements. Working with Dr. Kermode, Ms. Savoie has determined that stored protein within the endosperm and embryo is the main target for seed bug feeding. The greatest damage is caused by adult females and fourth instar nymphs, while almost no damage is caused by first and fifth instars. These data will be immediately useful for seed orchard managers in determining the timing of pesticidal treatments. Ms. Savoie has left for the Yukon, and is

pursuing a consulting career based in Whitehorse. A manuscript on this research has been submitted for publication in the Canadian Entomologist.

- A new student, Ms. Sarah Bates began her masters research project on the impact of *L. occidentalis* in May 1997. It is anticipated that this research will form the basis for a Ph.D. project to follow on completion of her M.P.M. degree. With the assistance of Orchard Manager Mr. Tim Crowder, a major field experiment was set up in May, 1997 at the Mt. Newton Seed Orchard, TimberWest Ltd., on Vancouver Island, to evaluate impact at different stages of cone development. To normalize impact, the experiment utilized genetically-identical trees of the same clone. Branch tips bearing 3 cones were bagged in mid-May to protect them from resident seed bugs. For 2-week periods in early June, early July and early August, groups of 6 nymphs (instars 2 and 3) were placed in a bag and allowed to feed. The nymphs were then removed and the branch tip was rebagged until the cones were harvested. To date the seed has been extracted and x-rayed, and SEM analyses will follow. Data on impact are not yet compiled. A similar experiment was set up during the late cone development stage in August to evaluate the impact in the field of feeding by *L. occidentalis* of different life stages. Previously bagged cones as above were exposed for two weeks to feeding by 3 adult males, 3 adult females or 6 nymphs. Again the experiment is still in the evaluation stage.
- Ms. Bates spends a considerable amount of time maintaining a laboratory colony of seed bugs. These bugs are used for laboratory experiments that will yield fed-on seed of various species for SEM studies to commence in the fall of 1997, and will supply similar seeds, as well as salivary gland extracts, for biochemical research on the impact of seed bug feeding. Finally Ms. Bates has confirmed observations by Ms. Savoie that a pentatomid bug, *Banasa sordida*, feeds readily on seed-bearing cones and extracted seed, particularly on western hemlock, western redcedar and yellow cedar. This bug was not previously known to be a pest of conifer seed production. Ms. Bates is attempting to establish a laboratory colony of these bugs for further study.
- Dr. Kermode and I were fortunate to be able to recruit a skilled plant physiologist-biochemist, Dr. Cameron Lait, who joined our program in September 1997, immediately after completing his

Ph.D. at the University of Alberta. He will focus primarily on the biochemistry of seed feeding by *Leptoglossus occidentalis*, it relates to specific seed storage proteins in several conifer species. Little is known about the biochemistry of feeding and subsequent seed storage protein damage caused by this insect pest. Seed proteins will be examined by SDS PAGE analysis and compared to seeds which have been fed on, in order to gain a better understanding about the specificity of the insect's feeding enzymes for proteins, carbohydrates, and lipids which are present in conifer seeds. The types of enzymes (proteins such as carbohydrases, proteases, kipases) used by *L. occidentalis* while feeding on conifer seeds are not understood and thus it is difficult to diagnose damage attributed to this pest, except through costly and labour-intensive examination (x-ray and SEM) of individual seeds. It is hoped that protein, carbohydrate and lipid analysis done using seeds fed on by *L. occidentalis* will allow us to identify some of the seed bug's salivary enzymes, and will help to develop biochemical tests by which we can easily detect the cause and extent of damage caused to conifer seeds by feeding.

- Protein extracts have already been generated by previous *L. occidentalis* feeding experiments. Seeds have been split into two parts: embryo and megagametophyte. Protein profiles of embryo and megagametophyte samples collected from the feeding experiments have been obtained and will be compared with protein profiles of *L. occidentalis* salivary gland extracts to see it there are any detectable enzymes of insect origin present in seeds that have been fed on. These extracts will also be used to look for breakdown products of storage proteins, which would be visible and can be confirmed immunologically. These tests will also detect any protein which is not digested by the salivary gland enzymes, or removed (depleted significantly) when feeding is complete.
- Another area of proposed research involves salivary gland analysis. Excised salivary glands will be examined by SDS PAGE to determine the quantity of proteins and complexity of the protein profile. It could be possible to produce a polyclonal antibody against salivary gland extracts to aid the search for a specific marker(s) for the presence of the bug in a particular seed. A search will be made for proteases (endo and exo), lipases, cell wall hydrolases, possibly amylases (probably not important), and pectinases. Enzyme extracts generated from salivary glands of insects will be

preserved, so they can be used *in vitro* with protein extracts generated from non-fed-on seeds to see if hydrolase extracts are active against authentic substrates. A final area of study will be to determine if extracts from cereal/legume seeds known to contain specific insect protease inhibitors are able to prevent *Leptoglossus*-induced hydrolysis of conifer protein reserves *in vitro* as a prelude to possible genetic engineering experiments.

E. PESTS OF CONIFER NURSERIES

- Research Associate Dr. Aileen Wardle has continued to work in collaboration with two members of SFU's Chemistry Department Dr. Keith Slessor and Ph.D. student Mr. Scott Baird on the sex pheromone of the tarnished plant bug, *Lygus lineolaris*. Lygus bugs have emerged as major pests of conifer nurseries, causing seedlings to be stunted and deformed, and rejected as culls. The pheromone work requires exceedingly exacting chemical analyses, and meticulously conducted bioassay experiments. The sex pheromone is present in sub-nanogram levels in female bugs and has been isolated in a very small portion of the extracts of females. The active constituents are partially identified, and a selection of potential synthetic analogues has been obtained for comparison with the natural materials. In anticipation of success with *L. lineolaris*, a colony of a local B.C. species, *L. schuli*, has been successfully established. A manuscript based on earlier work on the alarm pheromone of *L. lineolaris* has been prepared for internal review prior to submission to the Journal of Chemical Ecology.

F. BIODIVERSITY

- Maintenance of biodiversity is increasingly recognized as the responsibility of both the forest industry and government, and the knowledge that good environmental stewardship is practiced is now recognized as essential for the acceptance of forest products in environmentally-sensitive markets. Exotic insect pests can threaten the preservation of biodiversity. The poplar and willow borer, *Cryptorhynchus lapathi*, is an exotic pest that has decimated willow throughout much of B.C. Because willows are not economically harvested, this weevil has been largely ignored.

However, its potential impact on browse for wildlife and on the integrity and diversity of riparian zones now demands that it be more closely studied. Therefore, a new MPM student Ms. Cindy Broberg began to conduct research on *C. lapathi*, commencing in May 1997. Ms. Broberg is conducting a province-wide study of the impact of *C. lapathi* for her masters project. This is being done in five biogeoclimatic zones and 15 subzones. In each subzone there are three locations, with three sites per location, and five willow trees (clumps) per site. The existence of past and current weeviling is being documented, the impact of the weevil on mortality of its hosts is recorded, and the effect on host growth and form is measured.

- Concurrent with her masters project, Ms. Broberg has established a colony of wild-collected weevils, and has begun to conduct experiments on the chemical ecology of host selection and pheromone-based communication of *C. lapathi*. These experiments will form the basis of a proposed Ph.D. research project.

III. PUBLICATIONS AND PATENTS, 1 October 1996 to 30 September 1997.

The publications listed in this section pertain only to forestry. I am wrapping up several agricultural projects, but have not reported publications arising from them.

A. PAPERS IN REFEREED JOURNALS

1. Bowers, W.W., J.H. Borden and A.G. Raske. 1996. Bionomics of the four-eyed spruce bark beetle, *Polygraphus rufipennis* (Kirby) (Col., Scolytidae) in Newfoundland. I. Emergence and flight patterns. J. Appl. Entomol. 120: 449-461.
2. Bowers, W.W., J.H. Borden and A.G. Raske. 1996. Bionomics of the four-eyed spruce bark beetle, *Polygraphus rufipennis* (Kirby) (Col., Scolytidae) in Newfoundland. II. Host colonization sequence. J. Appl. Entomol. 120: 449-461.
3. Wilson, I.M., J.H. Borden, R. Gries and G. Gries. 1996. Green leaf volatiles as antiaggregants for the mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytidae). J. Chem. Ecol. 22: 1861-1875.

4. Miller, D.R., J.H. Borden and K.N. Slessor. 1996. Enantiospecific pheromone production and response profiles for populations of the pine engraver, *Ips pini* (Say) (Coleoptera: Scolytidae) in British Columbia. J. Chem. Ecol. 22: 2157-2172.

5. Blatt, S.E. and J.H. Borden. 1996. Distribution and impact of *Leptoglossus occidentalis* Heidemann (Hemiptera: Coreidae) in British Columbia seed orchards. Can. Entomol. 128: 1065-1076.

6. Tomlin, E.S. and J.H. Borden. 1997. Thin bark and high density of outer resin ducts: interrelated resistance traits in Sitka spruce against the white pine weevil. J. Econ. Entomol. 90: 235-239.

7. Macias-Samano, J.E., J.H. Borden, H.D. Pierce, Jr., R. Gries and G. Gries. 1997. Aggregation pheromone of *Pityokteines elegans* (Swaine) (Coleoptera: Scolytidae). J. Chem. Ecol. 23: 1333-1347.

8. Tomlin, E.S. and J.H. Borden. 1997. A multicomponent index for evaluating resistance by Sitka spruce to the white pine weevil. J. Econ. Entomol. 90: 704-714.

9. Tomlin, E.S. and J.H. Borden. 1997. Relationship between volatile foliar terpenes and resistance of Sitka spruce to the white pine weevil. For. Sci. (in press).

10. Poland, T.M. and J.H. Borden. 1997. Responses of a bark beetle predator, *Thanasimus undatulus* Say (Coleoptera: Cleridae), to pheromones of the spruce beetle and two sympatric bark beetle species (Coleoptera: Scolytidae). J. Entomol. Soc. B.C. (in press).

11. Borden, J.H., L.J. Chong, A. Savoie and I.M. Wilson. 1997. Responses to green leaf volatiles in two biogeoclimatic zones by the striped ambrosia beetle, *Trpodendron lineatum* (Olivier) (Coleoptera: Scolytidae). J. Chem. Ecol. (in press).

12. Savoie, A., J.H. Borden, H.D. Pierce, Jr., R. Gries and G. Gries. 1997. Aggregation pheromone of *Pityogenes knechteli* Swaine (Coleoptera: Scolytidae) and semiochemical-based interactions with three other bark beetles. J. Chem. Ecol. (in press).

13. Tomlin, E.S., R.I. Alfaro, J.H. Borden and F. He. 1997. Histological response of resistant and susceptible white spruce to simulated white pine weevil damage. Tree Physiology (in press).

14. Poland, T.M. and J.H. Borden. 1997. Disruption of secondary attraction of the spruce beetle, *Dendroctonus rufipennis* Kirby, by pheromones of two sympatric secondary species (Coleoptera: Scolytidae). J. Chem. Ecol. (in press).
15. Macias-Samano, J.E., J.H. Borden, R. Gries, H.D. Pierce, Jr., G. Gries and G.G.S. King. 1997. Primary attraction of the fir engraver, *Scolytus ventralis* LeConte (Coleoptera: Scolytidae). J. Chem. Ecol. (in press).
16. Camacho, A.D., H.D. Pierce, Jr. and J.H. Borden. 1997. Host compounds as kairomones for the western balsam bark beetle, *Dryocoetes confusus* (Coleoptera: Scolytidae). J. Appl. Entomol. (in press).
17. Partridge, M.J. and J.H. Borden. 1997. Evaluation of neem seed extract for control of the spruce aphid, *Elatobium abietinum* Walker (Homoptera: Aphididae). Can. Entomol. (in press).

B. CHAPTERS IN BOOKS

1. J.H. Borden. 1996. Disruption of semiochemical-mediated aggregation in bark beetles (Coleoptera: Scolytidae). pp. 421-438. In: Pheromone research: new directories. R.T. Cardé and A.K. Minks (eds.). Chapman and Hall, N.Y.

C. NON-REFEREED PUBLICATIONS

1. Savoie, A., J.H. Borden, S.E. Blatt, A.R. Kermode and R.G. Bennett. 1996. Damage caused by the western conifer seed bug, *Leptoglossus occidentalis* (Hemiptera: Coreidae) to Douglas-fir seeds. Seed and Seedling Extension Topics, B.C. Min. For. 9(2): 8-10.
2. Alfaro, R.I., E. Tomlin, J.H. Borden and F. He. 1996. Screening spruce for genetic resistance to white pine weevil. pp. 42-43. In: Tree Improvement Council of British Columbia, Progress Report to 1996. M. Crown and D. Reid (compilers). B.C. Min. For., Victoria, B.C.

D. PATENT

1. Borden, J.H., L.J. Chong, G. Gries, R. Gries, D.P.W. Huber, H.D. Pierce, Jr. and I.M. Wilson. 1996. Non-host volatiles as disruptants for bark beetles. Provisional U.S. Patent Application filed in December, 1996.

E. LETTER TO THE EDITOR

1. The Vancouver Sun, 19 August, 1997.

IV. PROFESSIONAL CONTRIBUTIONS (J.H. Borden, 1996-7)

1. Member, Forest Health Committee of B.C. Attended two-day meeting in Nelson, B.C., 13-14 May, 1997.
2. Member, Western Forest Insect Work Conference, Founders' Award Committee (resigned May, 1997).
3. Member, Program Committee, Annual Meeting of the International Society of Chemical Ecology, held from 13-16 July, 1997 in Vancouver, B.C. Chair of symposium on bark beetle pheromones.
4. Member, Committee of Forest Research Agencies of B.C.
5. Member, Advisory Committee, Agriculture and Agri-Food Canada Research Station, Summerland, B.C. Attended meetings in Summerland on 26 March and 12 September, 1997.
6. Member, Advisory Committee, Centre for Forest Biology, University of Victoria.
7. Member, Program Committee, Second International Symposium on Insect Pheromones, to be held in Wageningen, the Netherlands, 30 March - 3 April, 1998. Co-chair of session on applied use of pheromones.
8. Member, NSERC Site Visit Committee to the University of Guelph, 22-23 January, 1997.
9. Member, Advisory Committee to Department of Chemical Ecology, International Centre of Insect Physiology and Ecology, Nairobi, Kenya, appointed September 1997.

10. Director, Chemical Ecology Research Group, SFU.
11. Faculty in Charge of Insectary, SFU.
12. Senior Supervisor (current) of three Ph.D. students, one M.Sc. student and five M.P.M. students.
13. Served on Supervisory Committee of two M.P.M. and one M.Sc. student who graduated since 1 October, 1996.
14. Currently on Supervisory Committee of seven Ph.D. students, six M.P.M. students, and one undergraduate Honours student.
15. Sponsoring Forester for five Foresters in Training, Association of B.C. Professional Foresters.
16. Public Examiner for two M.P.M. theses since 1 October, 1996.
17. Tenure and promotion reviewer for Faculty of Forestry, Oregon State University, Fall 1996.
18. Reviewer of two research grant proposals, one from NSERC and the other from the U.S. National Science Foundation since 1 October, 1996.
19. Since 1 October, reviewed manuscripts for the following journals: Entomologia Experimentalis et Applicata (2), Canadian Journal of Forest Research (3), Environmental Entomology, Naturwissenschaften, Journal of Chemical Ecology, and The Canadian Entomologist.
20. Member, University Tenure Committee, SFU, 1995-7.
21. Member, M.P.M. Admissions Committee, 1986-present.
22. Presented invitational lectures at: the University of Guelph, January 1997; the 25th Anniversary Meeting of SFU's Centre for Pest Management, April 1997; and the Annual Meting of the International Society of Chemical Ecology, Vancouver, B.C., July 1997.
23. Senior or co-author of eight submitted papers at various scientific meetings since 1 October 1996. Invited discussant at Western Forest Insect Work Conference, Prince George, B.C., April 1997.
24. Consultant (unpaid) to Slocan Forest Products, Bugbusters Pest Management Inc., and the B.C. Forest Service on forest decline following spruce budworm defoliation, Fort Nelson, B.C. 29-30 September, 1997.

25. Letters written since 1 October 1997 to: Canadian Pest Management Regulatory Agency critiquing Draft Guidelines for the Research and Registration of Pest Control Products Containing Pheromones and Other semiochemicals; Forest Renewal B.C., one letter suggesting greater participation in NSERC's CRD program, and another critiquing policy on protection of intellectual property; the Vancouver Sun commenting on the need for rapid response to bark beetle infestations in a response to a reported Forest Practices Board audit of MOF Lakes District.
26. Member, Editorial Board, Journal of Chemical Ecology.
27. Research program, opinion or activities featured in: the Vancouver Sun, April 1997; and Burnaby Now, August 1997.
28. Taught: BISC 602-5, Forest Pest Management in Summer Semester, 1997; and BISC 847-3, Pest Management in Practice in Fall Semesters, 1996 and 1997.
29. Maintained membership in eight scientific societies, and professional registrations in the Association of B.C. Professional Foresters, the Association of Professional Biologists of B.C., and the American Registry of Professional Entomologists.

V. GRADUATES

From 1 October 1996 to 30 September 1997, two Ph.D. candidates and four Master of Pest Management (M.P.M.) students (as listed below) finished their programs of study and research and defended their theses under my supervision.

M.A. DUTHIE

Degrees: B.Sc., U.Vic., M.P.M., SFU, April 1997

Thesis Title: Evaluation of a neem-based insecticide for control of the mountain pine beetle.

Present Position: Forest Entomologist, Bugbusters Pest Management Inc., Prince George, B.C.

T.K. KIMOTO

Degrees: B.Sc., SFU; M.P.M., SFU, April 1997

Thesis Title: Past infestations of the white pine weevil, *Pissodes strobi* (Coleoptera: Curculionidae) in naturally regenerated stands of the McGregor Model Forest, Prince George, British Columbia.

Present position: Field Technician, Bugbusters Pest Management Inc., Prince George, B.C.

T.M. POLAND

Degrees: B.Sc., M.P.M., SFU; Ph.D., SFU, May 1997

Thesis Title: Competitive interactions between the spruce beetle, *Dendroctonus rufipennis* Kirby, and two secondary species, *Ips tridens* Mannerheim, and *Dryocoetes affaber* Mannerheim (Coleoptera: Scolytidae).

Present Position: Research Entomologist, USDA Forest Service, East Lansing, Michigan

S.E. BLATT

Degrees: B. Agric., N.S. Agric. Coll.; Ph.D., SFU, June 1997

Thesis Title: Host selection, impact and chemical ecology of the western conifer seed bug, *Leptoglossus occidentalis* Heidemann (Hemiptera: Coreidae).

Present Position: Homemaker in Kingston, Ontario and applying for postdoctoral positions while husband studies for Ph.D.

E.K. DEGLOW

Degrees: B.Sc., SFU; M.P.M., SFU, June 1997

Thesis Title: Effects of green leaf volatiles on the response to aggregation pheromones by two species of ambrosia beetles.

Present Position: Pest Management Specialist, Phero Tech Inc., Delta, B.C.

R.R. SETTER

Degrees: B.Sc., SFU; M.P.M., SFU, August 1997

Thesis Title: Potential adjuvents to attractive baits for the spruce beetle, *Dendroctonus rufepennis* Kirby (Coleoptera: Scolytidae).

Present Position: Head, Entomology Department, Bugbusters Pest Management Inc., Prince George, B.C.

IV. RESEARCH PERSONNEL

Unlike the five Annual Reports for Phase I of the Chair, no personnel involved in agricultural research will be listed in this and subsequent reports for Phase II. Moreover, despite a very active continuing collaboration with Dr. Gerhard Gries, the junior chair appointee, no personnel pursuing independent research in his laboratory are listed.

A. POSTDOCTORAL PERSONNEL

H.D. PIERCE, Jr., University Research Associate

Degrees: B.Sc., Ph.D., Illinois.

Subject Area: Volatile capture and extraction, analytical and synthetic organic chemistry, advising graduate students.

A.R. WARDLE, Research Associate

Degrees: B.Sc., UBC; M.P.M., Ph.D., SFU.

Subject Area: Chemical ecology and management of lygus bugs.

E.S. TOMLIN, Postdoctoral Fellow

Degrees: B.Sc., Western Ontario; M.Sc., Guelph; Ph.D., SFU.

Awards: NSERC Postdoctoral Fellowship.

Subject Area: Resistance mechanisms in spruce against the white pine weevil.

R.L. MCINTOSH, Postdoctoral Fellow

Degrees: B.S.F., University New Brunswick; M.Sc., Ph.D., UBC.

Subject Area: Chemical ecology and management of wood-boring beetles.

C.G. LAIT

Degrees: B.Sc., U. Vic.; Ph.D., Alberta.

Subject Area: Biochemistry of impact of seed bug feeding on conifer seeds.

B. RESEARCH TECHNICIANS

L.J. CHONG

Degree: B.Sc., SFU.

Subject Area: Support services and coordination for research on chemical ecology and management of forest insects.

R. GRIES

Degree: M. Agr., Göttingen.

Subject Area: GC-EAD analysis, bioassays, maintenance of GC-EAD laboratory and coordination of laboratory services.

A. SAVOIE (1996-7)

Degree: B.Sc., McGill (MacDonald Campus), M.P.M., SFU.

Subject Area: Impact of the western conifer seed bug.

Present Position: Pest Management Consultant, Whitehorse, Yukon.

C. PH.D. STUDENTS IN COURSE

D.P.W. HUBER

Degrees: B.Sc., Univ. of Calgary.

Awards: NSERC Scholarship with supplement from the Canadian Forest Service.

Subject Area: Bioactivity and application of non-host volatiles against bark beetles.

J.E. MACIAS-SAMANO

Degrees: B.Sc., National Polytechnic Institute, Mexico; M.P.M., SFU.

Awards: WUS Scholarship; Mexican Ph.D. Studies Scholarship.

Subject Area: Chemical ecology of the fir engraver and interaction with its major competitor.

D. MASTER OF SCIENCE STUDENT IN COURSE

D.S. PURESWARAN

Degree: B. Sc., Madras Christian Coll.

Awards: SFU Graduate Fellowship.

Subject Area: Pheromone production dynamics of bark beetles, and role of tree and beetle volatiles in maintaining host specificity and reproductive isolation.

E. MASTER OF PEST MANAGEMENT STUDENTS IN COURSE

M.E. GREENWOOD

Degree: B. Sc., SFU.

Award: SFU Graduate Fellowship

Subject Area: Co-baiting of stands for spruce beetles and western balsam bark beetles.

L. HARDER

Degree: B. Sc., University of B.C.

Subject Area: Pre-logging baiting for and impact of the western balsam bark beetle in alternative silvicultural systems.

N.L. JEANS

Degree: B.Sc., SFU.

Award: GREAT Award, Science Council of B.C.

Subject Area: Development of an improved tree bait for the western balsam bark beetle.

S.L. BATES

Degree: B.Sc., Univ. Guelph.

Award: NSERC Graduate Scholarship

Subject Area: Impact assessment of the western conifer seed bug.

C.L. BROBERG

Degree: B.Sc., Okanagan Univ. Coll. in coop. with UBC.

Award: SFU Graduate Fellowship, Entomological Society of Canada Graduate Scholarship.

Subject Area: Impact and chemical ecology of the poplar and willow borer.

F. GRADUATE, UNDERGRADUATE AND HIGH SCHOOL RESEARCH ASSISTANTS

E. ANTONIJEVIC, B.Sc., SFU (left science to start a landscaping business).

D. ELM, Office Worker, SFU.

N.L. JEANS, B.Sc., Biological Sciences, SFU.

E.K. MORIN, Hastings Jr. Secondary School, Port Coquitlam.

K.A. HARDACKER, Biological Science major, SFU.

M.L. NORTON, Biological Science major, SFU.

C.H. SILVA, Environmental Science major, SFU.

J.D. ALLISON, Biological Science major, Univ. Guelph.

N.A. JENSEN, Environmental Science major, SFU.

M. JONES, Cariboo Secondary School, Burnaby.

G.J.A. YAKEL, Biological Science major, SFU.

S.L. BATES, B.Sc., Biological Sciences, Univ. Guelph.

C.L. BROBERG, B.Sc., Botany, Okanagan Univ. Coll.

VII. PHYSICAL RESOURCES

- Chair activities are principally housed in a 247 m^2 laboratory at SFU comprising a general purpose area with bench space and desks for 3 Postdoctoral Fellows and 5 Graduate Students. Shared with an apiculturist, who has 7 personnel of his own, this laboratory fills up between April and October with 14 summer student Research Assistants. Three of Dr. Slessor's students also use the laboratory. It is truly a "bee hive" of activity. In addition, the Chair maintains a 35 m^2 rearing room for bark beetles, wood-boring beetles and terminal weevils in SFU's Insectary Annex, occupies (at $1.00 per day) two additional 6 m^2 insect rearing rooms for lygus and seed bugs in the Annex, maintains a 13 m^2 olfactometer room, which also houses a laminar air flow hood for sterile procedures, and has access to a wind tunnel for behavioural research in a separate laboratory maintained by Dr. Gries. In an unexpected windfall, the Chair acquired an unused and deteriorating 27.5 m^2 house trailer for $1.00 from SFU's Geography Department. This trailer has been moved to a permanent location and is being adapted by Dr. McIntosh into a bulk-rearing facility for wood-boring beetles.
- The Chair absolutely depends on two laboratories in SFU's Department of Chemistry. These are a 30 m^2 laboratory in which Dr. and Ms. Gries conduct their world class GC-EAD analytical work, and a 100 m^2 laboratory in which Dr. Pierce performs volatile capture, extraction and analysis, and in which Dr. Grigori Khaskin does chemical syntheses under the

direction of Dr. Gries. Dr. Gries and I have received notice that in 1998, the Department of Chemistry intends to evict us from these laboratories, which were previously under the supervision of chemistry professors. Because loss of these facilities will make it impossible to achieve the Chair objectives, I and Dr. Gries have appealed to the Dean of Science for their retention. If we loose, the Chair could come to an early end.

- My laboratory maintains three pick up trucks (in addition to two leased vehicles under FRBC grants), two outdoor walk-in cold rooms for maintenance of insect and host material under winter conditions, 10 indoor environmental chambers, three freezers and several refrigerators (including a fire-proof model for dangerous chemicals), four chain saws, one generator and a large amount of field forestry equipment, hardware tools, and general minor laboratory equipment.
- In the fall-winter of 1997-8, we plan to replace an ancient gas chromatograph, and to purchase a two-dimensional GC unit and a considerable amount of analytical equipment needed by Dr. Kermode to conduct biochemical studies on the breakdown of conifer seeds fed on by seed bugs. We also plan to upgrade our laboratory computing capability and replace much of our inventory of worn-out multiple-funnel traps.
- In the spring of 1997, I entered into an agreement with Dr. Dai Jones of Pacific Cedar Industries (PCI) in Langley, B.C. for PCI to build and operate a 23 kg capacity steam distillation apparatus modelled after their 9-tonne stills for extraction of cedar oil from hog fuel. This "mini" still is being used to extract the bark of various host and non-host trees for testing against bark and woodboring beetles, to determine if natural bark extracts could be cheaper and more competitive attractants and disruptants than blends of expensive synthetic chemicals.

VIII. FINANCIAL SUMMARY

My original intention was to fund Phase II of the Research Chair almost solely from a CRD Grant package in which Forest Renewal B.C. would provide a $75,000 "industrial" contribution to match the $75,000 direct financial contribution from forest industries, and then exceed this amount by $250,126 to provide a total Chair budget of $550,126 when the $150,000 contribution from NSERC was included. However, Forest Renewal B.C. judged that this large contribution would constitute support of a Chair, which was not in their mandate at the time. I was therefore encouraged by Mr. Colin E. Smith, Chief Executive Officer of Forest Renewal B.C., to apply for additional funds on a project by project basis. Consequently I spent a great deal of time in the fall of 1996 preparing two separate proposals for research on wood-borers ($147,390) and, in collaboration with Dr. Allison Kermode, on the western conifer seed bug ($93,991). Both of these proposals were successful and in September, 1997 I received funding for both accounts retroactive to 1 April 1997. I also unexpectedly received a four-year NSERC Research Grant that will provide $40,000 per year commencing on 1 April 1997.

The following financial statement is unofficial, but I believe that it is accurate. It excludes all funding and expenditures for agriculturally-oriented research, and estimates with good precision the revenue and expenditures from 1 October 1996 to 30 September 1997, making adjustments for grants and contracts with start and end dates differing from the accounts in the NSERC CRD Grant package.

The unexpended balance of $29,063.28, together with revenue in the following year, will be used primarily to purchase new or replacement equipment that will facilitate the successful completion of laboratory and field experiments.

A. REVENUE

NSERC CRD Grant:

NSERC	$150,000	
Forest Renewal B.C.	75,000	
Industry, Direct Contributions	75,000	
Total CRD Package		$300,000

FOREST RENEWAL B.C. Grants (first 2 quarters only)

Wood-borers (FRBC ref. # PA97511-0RE)	$73,831	
Seed bugs (FRBC ref. #PA97510-0RE)	39,418	
Total FRBC		113,249

OTHER GRANTS

NSERC Research (first 2 quarters only)	$20,000	
Technology B.C. (through Phero Tech, last 2 quarters only)		
Direct industrial contributions	3,892	
Science Council B.C. contribution	9,580	
Canadian Forest Service (white pine weevil)	18,750	
Minor Service Contracts (last 2 quarters only)		
B.C. Forest Service (seed bugs)	18,842	
B.C. Forest Service (bark beetles)	8,750	
GREAT Award industrial contributions	7,500	
Total Other Grants		87,314
TOTAL REVENUE		$500,563

B. EXPENDITURES (1 October 1996 - 30 September 1997)

SALARIES AND BENEFITS

Research Associates and Postdoctoral Fellows	
H.D. Pierce, Jr.	$46,273.84
A.R. Wardle	30,178.68
E.S. Tomlin	5,520.00
R.L. McIntosh	10,170.82
C.G. Lait	2,455.02
Research Technicians	
L.J. Chong	34,672.93
R. Gries	34,947.47
A. Savoie	11,336.24
Graduate Students	
J.E. Macias-Samano	5,002.07
M.E. Greenwood	5,072.39
L. Harder	5,072.39
E.K. Deglow	5,072.39

Research Assistants		
J.D. Allison	8,279.28	
E. Antonijevic	3,875.00	
C.L. Broberg	8,279.28	
K.A. Hardacker	6,830.37	
D. Elm	829.00	
N.L. Jeans	1,800.00	
M.L. Norton	6,209.46	
C.H. Silva	6,830.37	
N.A. Jensen	5,864.49	
G.J.A. Yakel	5,843.76	
S.L Bates	8,279.28	
J. Li	3,545.53	
M. Jones	3,587.68	
E. Morin	135.00	
Total Salaries	265,961.74	
Benefits	29,306.12	
TOTAL SALARIES AND BENEFITS		$295,267.86
FIELD TRAVEL		79,444.98
GENERAL TRAVEL		6,895.13
EQUIPMENT		41,285.07
MATERIALS, SUPPLIES AND SERVICES		41,344.48
ADMINISTRATIVE COSTS AND OVERHEAD		7,262.20
TOTAL EXPENDITURES		$471,499.72

Budget Notes

Salary for E.S. Tomlin was paid by a grant from the Canadian Forest Service as a supplement to her NSERC Postdoctoral Fellowship. D.P.W. Huber and S.L. Bates are not listed under Graduate Students because they were wholly supported by NSERC Postgraduate Scholarships. In their first semester of graduate studies, C.L. Broberg and D.S. Pureswaran won SFU Graduate Fellowships and did not require salaries. The Graduate Student stipend of $1250 per mo. for the summer semester for Nicole Jeans was recovered by an FRBC grant to Phero Tech; commencing on 1 September 1997 Ms. Jeans will be supported by a GREAT Award from the Science Council of B.C. Coupled with reduced expenditures due to delayed start up on new FRBC grants, salary savings through outside support for these outstanding students are responsible for the positive balance below.

C. CURRENT FINANCIAL POSITION

Revenue	$500,563.00
Expenditures	471,499.72
Unexpended Balance	$ 29,063.28

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